DRAFT

Lower Virgin River-Boron Total Maximum Daily Loads

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Introduction

Section 303(d) of the Clean Water Act requires each state develop a list of waterbodies that need additional work beyond existing controls to achieve or maintain water quality standards, and submit an updated list to the Environmental Protection Agency (EPA) every two years. The Section 303(d) List provides a comprehensive inventory of water bodies impaired by all sources. This inventory is the basis for targeting water bodies for watershed-based solutions, and the TMDL process provides an organized framework to develop these solutions.

TMDLs are an assessment of the amount of pollutant a waterbody can receive and not violate water quality standards, and provide a means to integrate the management of both point and nonpoint sources of pollution through the establishment of wasteload allocations for point source discharges and load allocations for nonpoint sources. For pollutants other than heat, TMDLs are to be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards with consideration given to seasonal variations and a margin of safety. Once approved by the U.S. Environmental Protection Agency, TMDLs are implemented through existing National Pollutant Discharge Elimination System (NPDES) permits for point source discharges and nonpoint source control programs to achieve the necessary pollutant reductions. Nonpoint source TMDLs can be implemented through voluntary or regulatory nonpoint source programs, depending upon the state.

The lower Virgin River from the Nevada-Arizona stateline to Lake Mead is listed on Nevada's 1998 303(d) List for exceedances of the boron and total phosphorus water quality standards. This document discusses TMDL development for boron. Total phosphorus impairments on the Virgin River will be addressed in the future.

Background and Problem Statement

Study Area

The Virgin River, a tributary of the Colorado River, has its headwaters in the southwestern Utah, flows southwest into northwestern Arizona through a deep gorge in the Virgin Mountains, enters Nevada near Mesquite, Nevada and empties into the Overton Arm of Lake Mead in Nevada (Figure 1). A majority of the streamflow in the Virgin River originates upstream in Utah from snowmelt runoff. However, spring sources, groundwater discharges and ephemeral tributaries in the lower basin also contribute to the water supply.

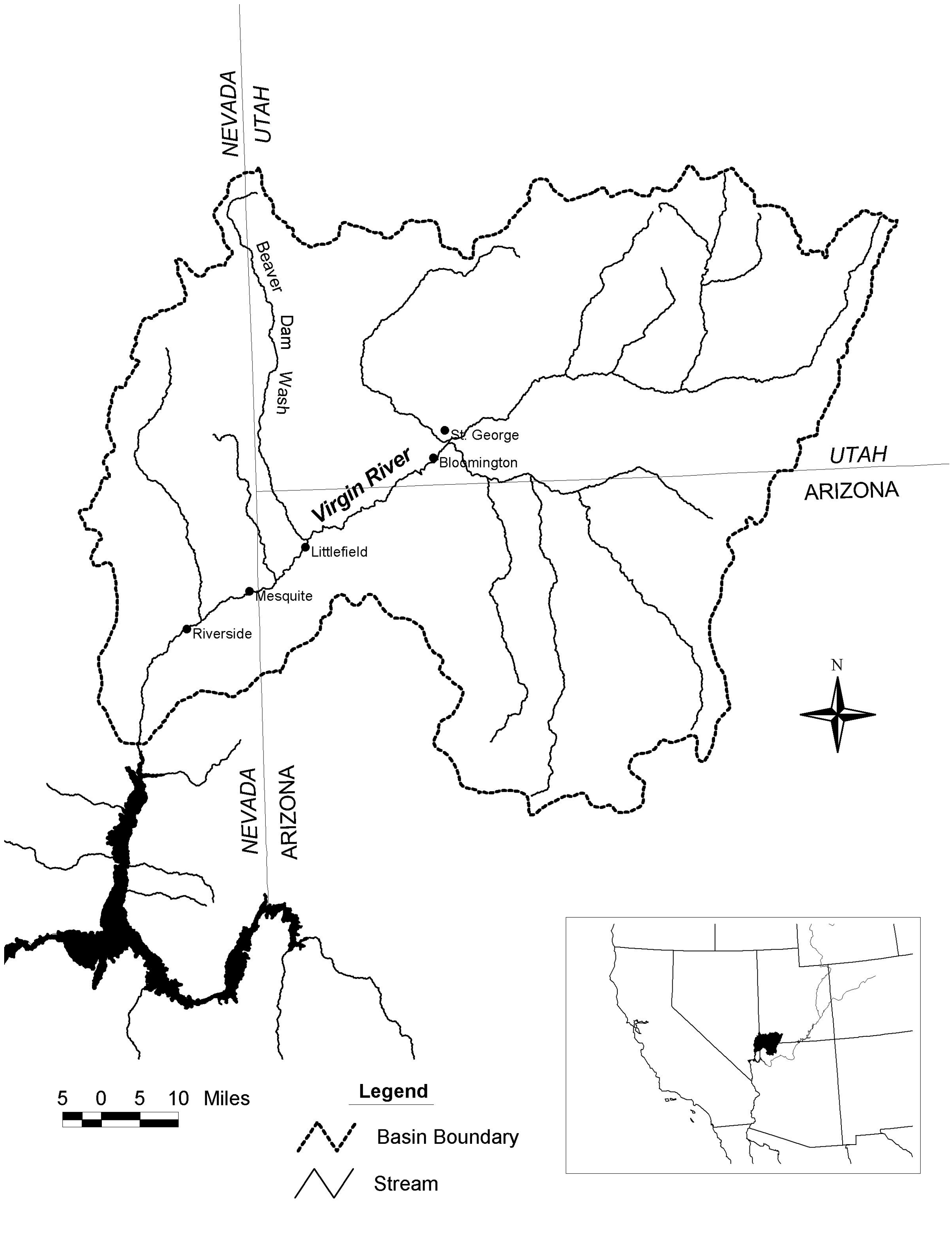


Figure 1. Virgin River Location Map

Water Quality Standards

Nevada's water quality standards, contained in the Nevada Administrative Code 445A.119 – 445A.225, define the water quality goals for a waterbody by: 1) designating beneficial uses of the water; and 2) setting criteria necessary to protect the beneficial uses. Beneficial uses include such things as irrigation, recreation, aquatic life, fisheries, irrigation and drinking water. The designated beneficial uses for the Virgin River include:

- Irrigation
- Watering of livestock
- Recreation not involving contact with water
- Industrial supply
- Propagation of wildlife
- Propagation of aquatic life

Both narrative and numeric criteria are included in Nevada's water quality standards. The narrative standards are applicable to all surface waters of the state and consist mostly of statements requiring waters to be "free from" various pollutants including those that are toxic. The numeric standards for conventional pollutants are broken down into two types: class and water body specific. For the class waters, criteria for various pollutants are designed to protect the beneficial uses of classes of water, from A to D; with class A being the highest quality. The water bodies belonging to these classes are named in the regulations.

For major waterbodies in Nevada, site specific numeric standards have been developed. These standards include both criteria designed to protect the beneficial uses and antidegradation requirements. The antidegradation is addressed through the establishment of "requirements to maintain existing higher quality" or RMHQs. RMHQs are set when existing water quality (as evidenced by the monitoring data) for individual parameters is higher than the criteria necessary to protect the beneficial uses. This system of directly linking antidegradation to water quality standards provides a manageable means for implementing antidegradation through the permit program and other programs.

The water quality standards divide the Lower Virgin River into two reaches, i.e. 1) from Nevada-Arizona Stateline to Mesquite, NV; 2) from Mesquite, NV to Lake Mead, with numeric standards for certain parameters[1]. NAC 445A.144 provides numeric criteria for "total recoverable" boron concentrations as needed to support two different beneficial uses (Table 1). Of the two criteria, the boron standard for irrigation uses is the most restrictive. According to the Gold Book (U.S. EPA, 1986), boron is an essential element for the growth of plants, however higher levels may have toxic impacts to sensitive crops. The criterion of 750 µg/l is thought to protect sensitive crops during long-term irrigation.

[1] NAC 445A.175 and NAC 445A.177 provide numeric standards for the Lower Virgin River for the following parameters: temperature, pH, total phosphates, nitrogen species, dissolved oxygen, turbidity, color, total dissolved solids, alkalinity and fecal coliform.

EPA has no recommended criteria for boron as needed for the support of aquatic life. The Gold Book (U.S. EPA, 1986) states that "naturally occurring concentrations of boron should have no effects on aquatic life."

Table 1. Boron (Total Recoverable) Standards Applicable to the Lower Virgin River

Beneficial Use	Numeric Standard (µg/l)	Source
Irrigation	750	Quality Criteria for Water (Gold Book), Pub. No. EPA 440/5-86-001.
Watering of Livestock	5,000	Water Quality Criteria (Blue Book), National Academy of Sciences

Source: NAC 445A.144

303(d) Listing

As discussed earlier, Section 303(d) of the Clean Water Act requires each state develop a list of waterbodies that need additional work beyond existing controls to achieve or maintain water quality standards, and submit an updated list to the Environmental Protection Agency (EPA) every two years. The Section 303(d) List provides a comprehensive inventory of water bodies impaired by all sources.

In general, a waterbody has been included on Nevada's 303(d) Lists if adequate data existed to document exceedance of the beneficial use standards more than 25 percent of the time. As part of a statewide ambient monitoring network, NDEP has collected grabs samples at two locations (Mesquite, NV and Riverside, NV) on the Virgin River since 1990. Table 2 summarizes the boron data collected by NDEP and exceedances of the boron standard for irrigation. Based upon NDEP's monitoring data, both reaches of the Lower Virgin River have been listed since 1994. The water quality of the Lower Virgin River is described in more detail in the ***Surface Water Characteristics*** Section.

According to EPA's Internet website on TMDL programs throughout the United States (http://www.epa.gov/owow/tmdl/index.html), the Virgin River is listed on the 303(d) Lists of Arizona and Utah for salinity, total dissolved solids and chlorides, and for turbidity, respectively. Neither state has listed the Virgin River for boron. In Arizona, the most restrictive Virgin River boron standard has been set at 1,000 µg/l (total recoverable[2]) for agricultural irrigation uses. Based upon 1999 data collected by the U.S. Geological Survey at Littlefield, Arizona, none of the samples had boron concentrations greater than 1,000 µg/l standard (Marsh, 2000). However, a number of earlier (pre-1982) samples had boron concentrations exceeding the 1,000 µg/l standard. It must be noted that the USGS data include only dissolved boron concentrations rather than total recoverable concentrations used in the water quality standards.

[2] Total recoverable boron includes both dissolved and undissolved boron.

Table 2. Lower Virgin River – Exceedances of Boron Water Quality Standard for Irrigation, 1990-99

Reach (NAC)	Reach Description	Sampling Location	Applicable 303(d) List[1]	Sampling Period	Number of Samples[2]	Percent of Samples exceeding Boron Standard (750 µg/l)
445A.175	NV-AZ Stateline to Mesquite, NV	Virgin River at Mesquite, NV	1992	1990-91	3	100%
			1994	1992-93	4	75%
			1996	1994-95	5	60%
			1998	1996-97	7	60%
			See Note 3	1998-2001	4	71%
445A.177	Mesquite, NV to Lake Mead	Virgin River at Riverside, NV	1992	1990-91	3	100%
			1994	1992-93	4	75%
			1996	1994-95	5	60%
			1998	1996-97	5	60%
			See Note 3	1998-2001	7	57%

[1] In developing the 303(d) Lists, NDEP has used data for the previous two years.

[2] A minimum of four samples is required (by NDEP) for listing.

[3] The next 303(d) List is scheduled for 2002. However, the sampling period to be used is yet to be determined

Surface Water Quantity and Quality Characteristics

Primary Monitoring Stations. Table 3 provides a list of the primary streamflow gaging stations and water quality monitoring stations in the Lower Virgin River Basin (Figure 2). Data collected at these stations were the primary source of flow and boron (total and dissolved) concentration information utilized in the development of this report. Refer to Appendix A for detailed boron concentration data.

Water Quantity. Surface water in the Virgin River is comprised of direct runoff from rainfall and snowmelt, and from groundwater entering from springs. The water from melting snow makes up the largest percentage of streamflow and usually causes the high monthly flows to occur in March through May (Figure 3). Years of above average snowpack in the mountains directly correlate to years of above average flow in the streams (USDA, 1990). Lower streamflows generally occur from June through November. Average daily flows at Littlefield, Arizona have ranged from a minimum of 40 cfs to a maximum of 17,000 cfs, with a median daily flow of about 150 cfs (Figure 4). A majority of the low flow periods occur from June through October.

A majority of the streamflow in the Nevada portion of the Virgin River originates upstream in Utah and Arizona. Additional sources of flow to the river in the lower basin are Littlefield Springs, Petrified Springs, springs in Beaver Dam Wash, and ground-water discharge along the

Table 3. List of Selected Water Quantity and Water Quality Monitoring Stations

STORET ID	Description	Agency	Period of Record	Parameters
Streamflow Gaging Stations				
9413200	Virgin River near Bloomington, UT	USGS	1977-98	Flow
9413500	Virgin River near St. George, UT	USGS	1951-57, 1992-96, 1998	Flow
9413700	Virgin River above the Narrows near Littlefield, AZ	USGS	1998	Flow
9415000	Virgin River at Littlefield, AZ	USGS	1930-98	Flow
9415190	Virgin River at Riverside, NV	USGS	1971-74, 1993-96	Flow
9415230	Virgin River at Halfway Wash near Riverside, NV	USGS	1978, 1980-83, 1985	Flow
Water Quality Monitoring Stations				
9413300	Virgin River at Bloomington, UT	USGS	1978-79	Dissolved Boron, Flow
9413600	Virgin River above I15 Rest Area near Littlefield, AZ	USGS	1977-79	Dissolved Boron, Flow
9413650	Virgin River below I15 Rest Area near Littlefield, AZ	USGS	1977-79	Dissolved Boron, Flow
9413800	Virgin River at Mouth of Narrows near Littlefield, AZ	USGS	1977-79	Dissolved Boron, Flow
9415000	Virgin River at Littlefield, AZ	USGS	1954-82, 1999	Dissolved Boron, Flow
310037	Virgin River at Mesquite, NV	Nevada	1990-2001	Total Boron (Dissolved Boron – 2000-01 only)
310032	Virgin River at Riverside, NV	Nevada	1990-2001	Total Boron (Dissolved Boron – 2000-01 only)

river (Las Vegas Valley Water District, 1992). According to a study by the Southern Nevada Water Authority (SNWA, 2000), the source of the Littlefield Springs is upstream seepage water from Virgin River water partially mixed with deeper ground water. SNWA theorized that the travel time for the Virgin River component of the Springs flow is about 20 to 24 years.

Numerous springs, primarily located upstream of Littlefield, Arizona, maintain the Virgin River's baseflow and provide most of the river flow entering Nevada during low-flow periods. Glancy and Van Denburgh (1969) identified two main perennial spring systems in the Lower Virgin River area: springs (Littlefield Springs and Petrified Springs) located along a several mile section of the Virgin River upstream of the Littlefield, Arizona (Las Vegas Valley Water District, 1992); and the springs and groundwater flow in Beaver Dam Wash, which enters the Virgin River just upstream of Littlefield (see Figure 1). Under baseflow conditions, Littlefield Springs contributes about 65 cfs with the springs in Beaver Dam Wash and the Petrified Springs contributing another 5 cfs. Therefore, the water quality of the Lower Virgin River during low flow conditions is highly reflective of the Littlefield Springs water quality (Las Vegas Valley Water District, 1992).

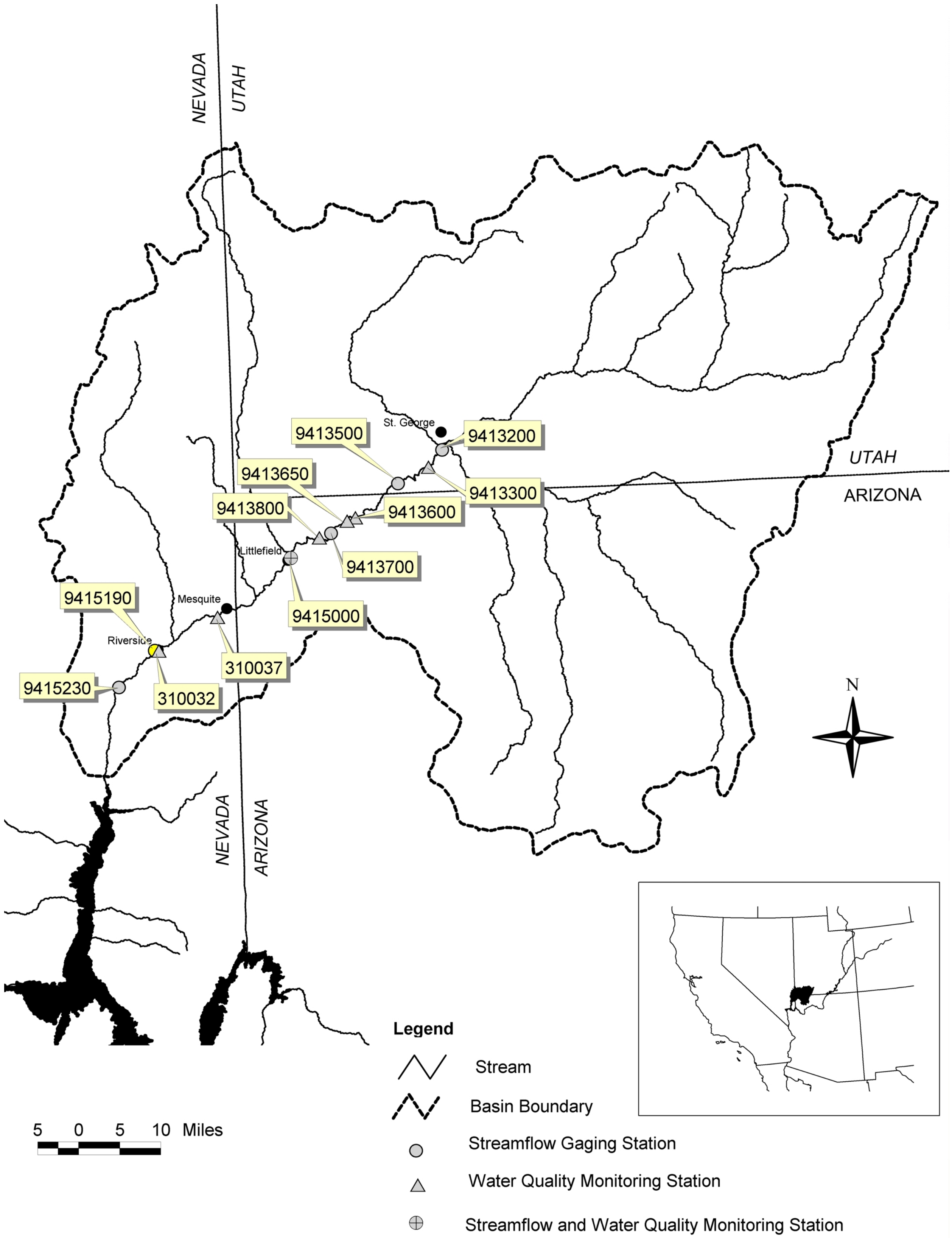


Figure 2. Selected Water Quantity and Quality Monitoring Stations

Figure 3. Average Monthly Streamflow - Virgin River at Littlefield, AZ (09415000)

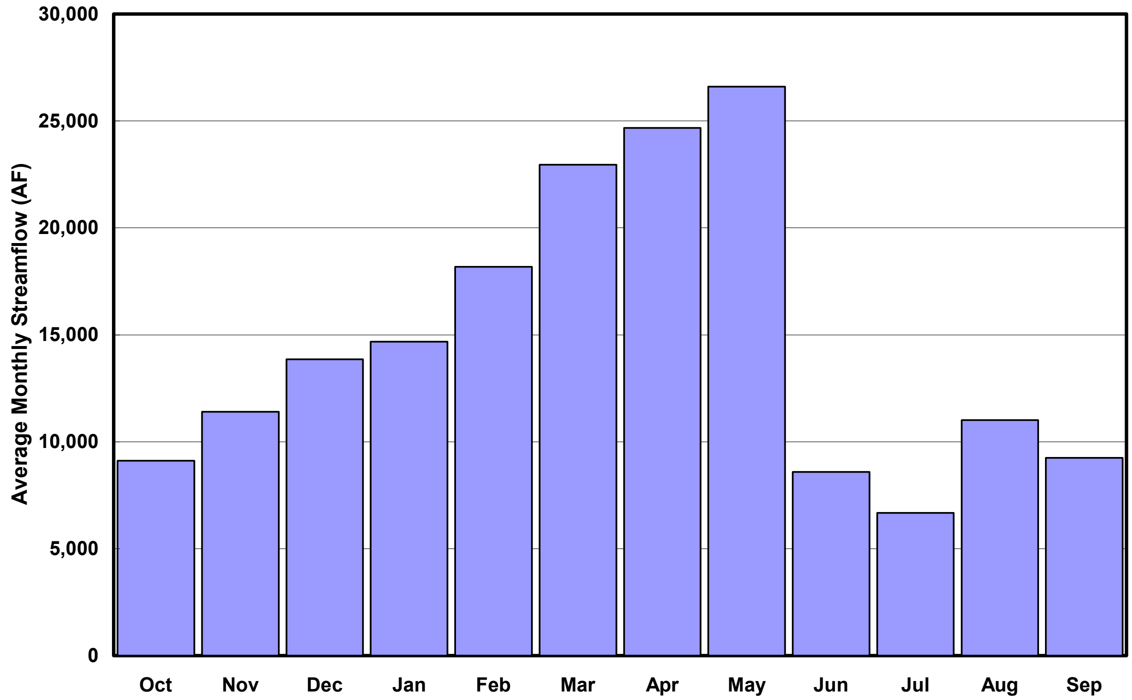
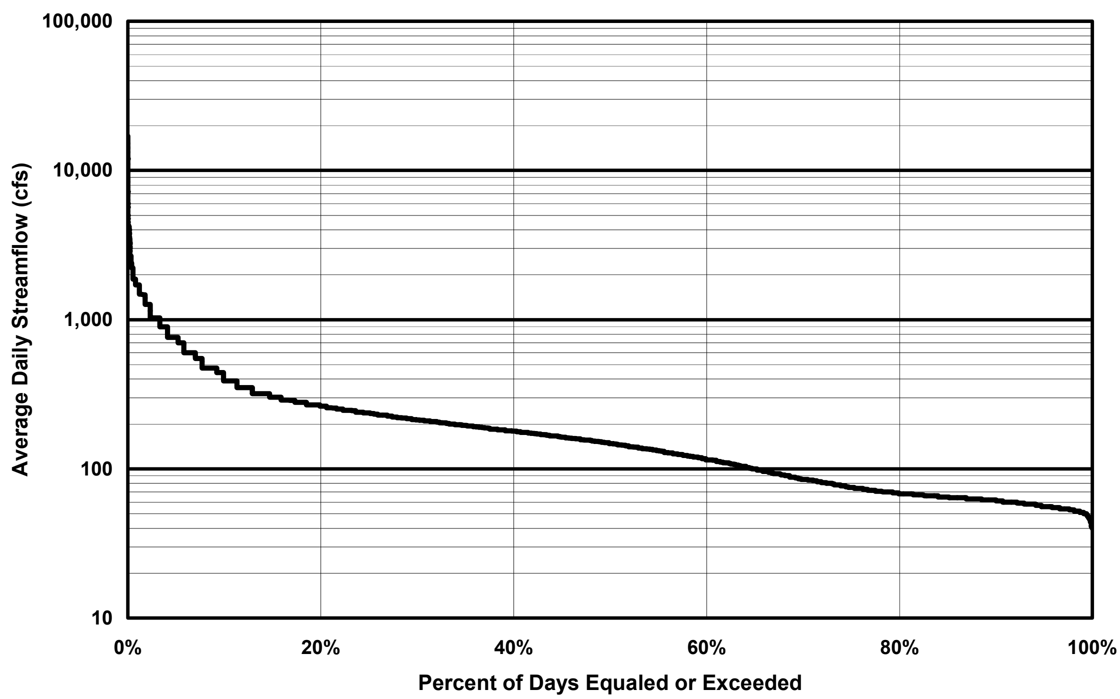


Figure 4. Flow Duration Curve - Virgin River at Littlefield, AZ (1930-98)



A streamflow budget diagram presented by the Utah Board of Water Resources (1993) shows that average annual Virgin River flows increase as one moves from the headwaters downstream to the Littlefield gage. In general, Virgin River surface water flows decrease between the USGS gaging station at Littlefield, Arizona to the river mouth at Lake Mead (Table 4). For the period 1930-67, Glancy and Van Denburgh (1969) estimated that average annual flows decreased from 162,200 acre-feet per year at Littlefield, Arizona to about 123,000 acre-feet at the river mouth (including subsurface flow), primarily due to phreatophyte evapotranspiration (approximately 35,000 acre-feet per year) and irrigation consumptive uses (approximately 15,000 acre-feet per year). Minor additional water enters the Virgin River between the Nevada-Arizona stateline and Lake Mead. Glancy and Van Denburgh (1969) estimated local runoff in this reach to average 5,000 acre-feet per year. Groundwater discharges and irrigation return flows also contribute to the flow in the lower river (Las Vegas Valley Water District, 1993). A quantification of these flow contributions was not found in the available literature. However, a reasonable estimate of irrigation return flows could be about 15,000 acre-feet (assuming crop consumptive use is 15,000 acre-feet per year and irrigation efficiency is 50 percent).

Table 4. Historic and Estimated Average Annual Flows at Selected Gaging Stations on the Virgin River

STORET ID	Description	Historic Average Annual Flows		Historic/Estimated Average Annual Flow (1930-98), acre-feet[1]
		Period of Record	Average Annual Flow, acre-feet	
9413200	Virgin River near Bloomington, UT	1977-98	182,600	142,800
9413500	Virgin River near St. George, UT	1951-57, 1992-96, 1998	147,300	135,300
9415000	Virgin River at Littlefield, AZ	1930-98	177,000	177,000
9415190	Virgin River at Riverside, NV	1971-74, 1993-96	218,400	156,200
9415230	Virgin River at Halfway Wash near Riverside, NV	1978, 1980-83, 1985	244,100	134,200

[1] The estimated average annual flows were developed by: 1) performing linear regression analyses between the historic average annual flows for the gaging station in question versus the historic flows for the Littlefield gage; and 2) applying the subsequent linear regression equation to the Littlefield gaged data to estimate average annual flows for the missing years (see Appendix A).

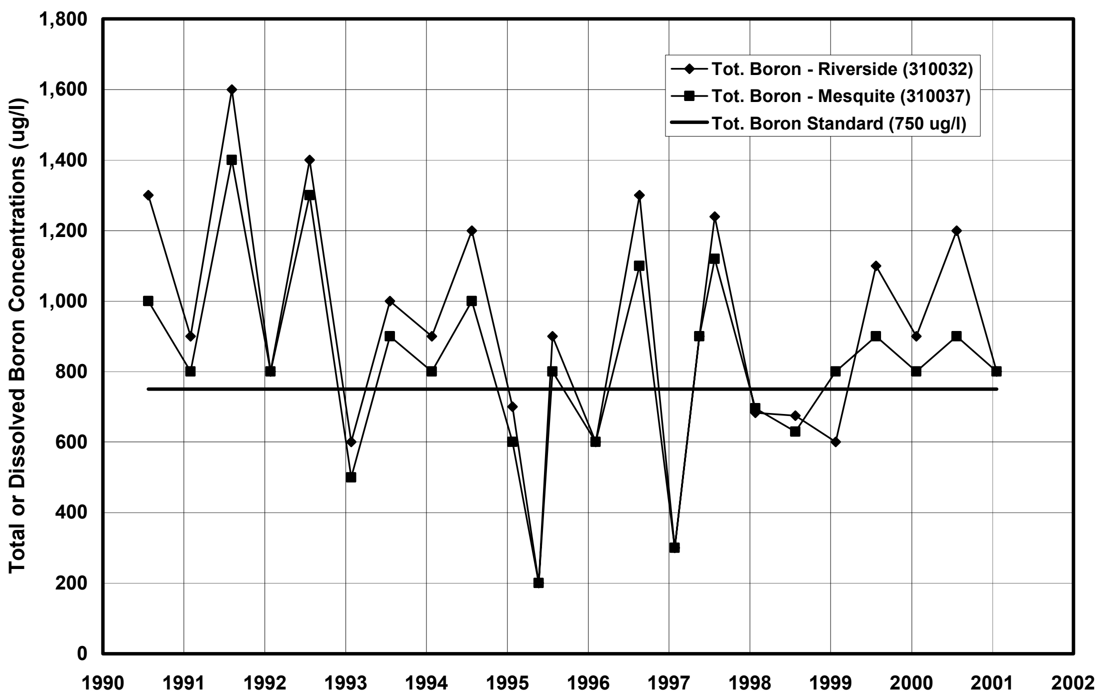
<u>Water Quality – Boron</u>: As discussed earlier, the lower Virgin River is included on Nevada's 1998 303(d) List due to exceedances of the boron standard for irrigation. The listing decision was based upon water chemistry analyses on grab samples collected by NDEP at Mesquite and Riverside. Of the 48 samples collected at these sites between July 1990 and January 2001, about 70 percent had total boron concentrations greater than the 750 µg/l standard (Table 5). Figure 5 shows the variability of the boron concentrations from sample to sample at the two NDEP sites. It must be noted that the NDEP data are not completely representative of conditions throughout the year. A majority of the samples have been collected during the months of January, July and August, typically low flow periods.

Table 5. Summary of Boron Standard Exceedances at Selected Stations

Station	Period of Record	Dissolved or Total Boron	Number of Samples	Exceedances of Boron Standard (750 µg/l)	
				Number	Percentage
9413300 – Bloomington	1978-79	Dissolved	14	5	36
9413600 – Ab. I15 Restarea	1977-79	Dissolved	17	1[1]	6
9413650 – Bel. I15 Restarea	1977-79	Dissolved	17	1[1]	6
9413800 – Mouth of Narrows	1977-79	Dissolved	25	14	56
9415000 – Littlefield	1954-82, 1999	Dissolved	103	57	55
310037 – Mesquite	1990-2001	Total	24	17	71
310032 – Riverside	1990-2001	Total	24	16	67

[1] Number of exceedances were lower at these stations due to the lack of sampling during low flows in the Summers of 1978 and 1979.

Figure 5. Boron Concentrations at Riverside and Mesquite , 1990-2000



Other data collected by the USGS indicate high dissolved boron concentrations in the Virgin River upstream in both Utah and Arizona. Figure 6 displays additional boron data developed by the USGS for the Littlefield station for 1954 through 1982. Recently (1999), the USGS resumed testing for dissolved boron at Littlefield. Of the more than 100 samples collected from 1954 through 1999, over 50 percent had dissolved boron concentrations greater than the 750 ug/l standard (Table 5). During the period 1977-79, boron data were collected at sites upstream of Littlefield. These data also show significant exceedances of the boron standard (Table 5; Figure 7).

Figure 6. Dissolved Boron Concentrations at Littlefield, AZ (1954-1982)

As previously stated, Littlefield Springs contributes about 65 cfs with the springs in Beaver Dam Wash and the Petrified Springs contributing another 5 cfs during low flow conditions. Therefore, the water quality of the Lower Virgin River during low flow conditions is highly reflective of the Littlefield Springs water quality (Las Vegas Valley Water District, 1992). No boron concentration data for the Littlefield Springs discharge could be found in the literature, however, the Arizona Department of Environmental Quality (1999) has performed groundwater sampling in the area. In this study, ADEQ found boron in the Littlefield aquifer with a median concentration of about 1,100 µg/l. Samples collected in the Virgin River alluvium had a median boron concentration of about 800 µg/l.

Without exception, the data from all seven water quality monitoring stations identified in Table 3 show that boron concentrations increase with decreases in streamflow (Figure 8). In fact, most of the boron standard exceedances occurred during periods of flow less than 50 to 175 cfs (Table 6).

Figure 7. Dissolved Boron Concentrations Upstream of Littlefield, 1977-1979

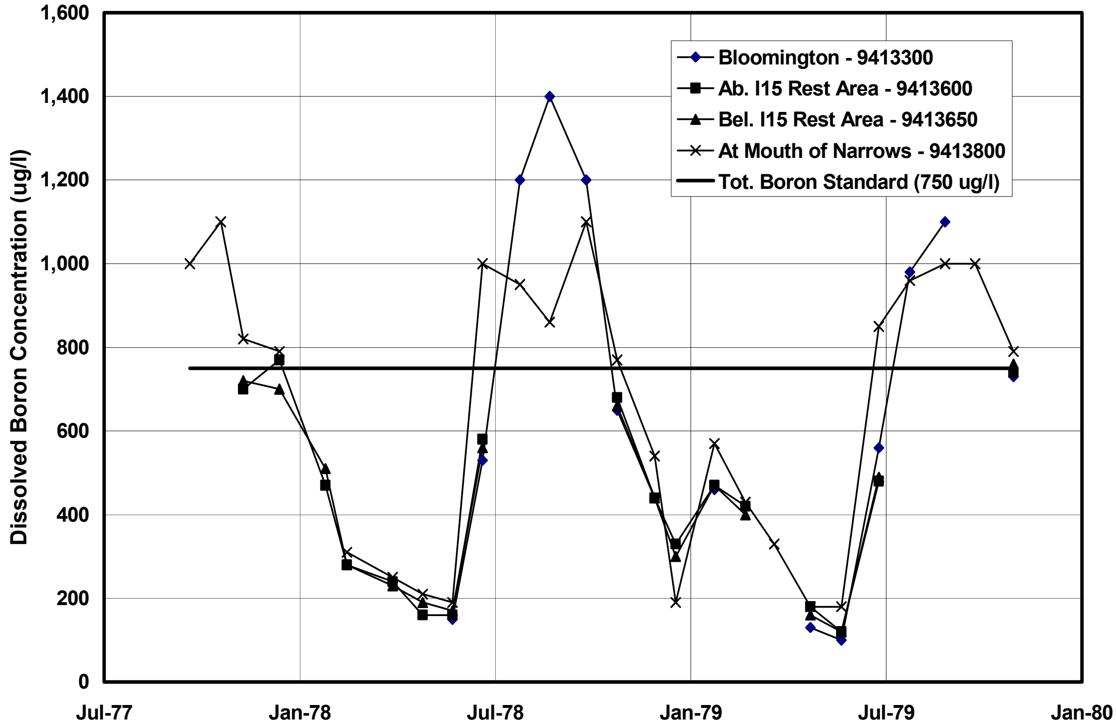


Figure 8. Boron Concentrations versus Streamflow at Primary Monitoring Sites

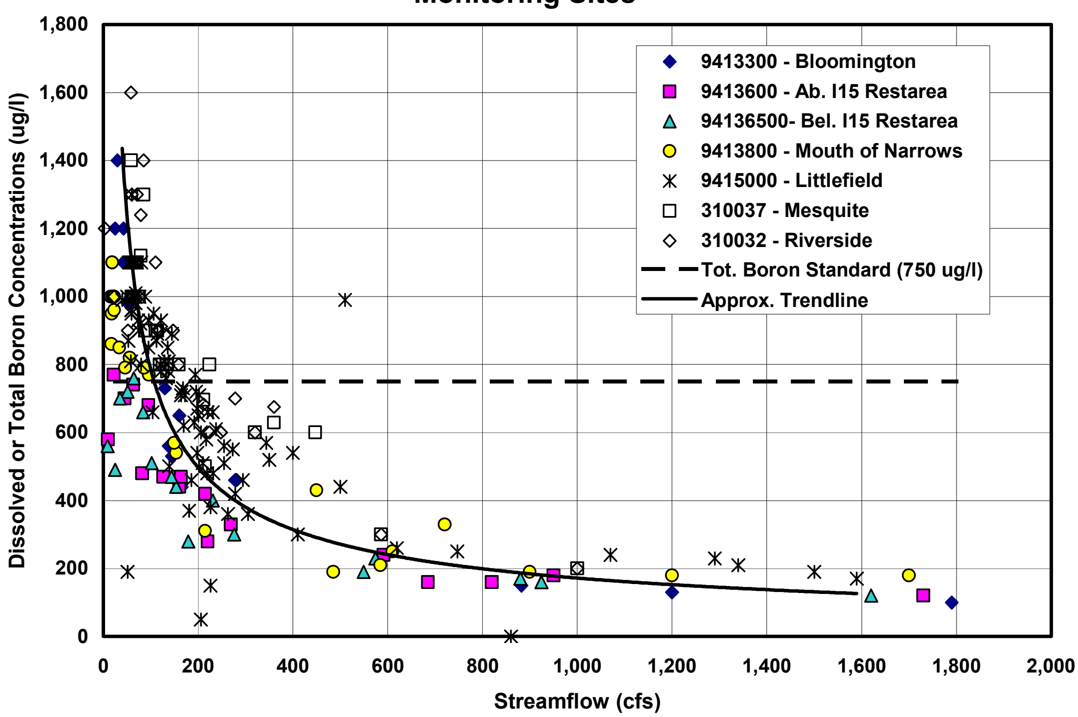


Table 6. Summary of Boron Standard Exceedances and Concurrent Maximum Streamflows

Station	Number of Samples	Exceedances of Boron Standard (750 µg/l)		95% of Boron Standard Exceedances Occurred at or Below this Flow (cfs)
		Number	Percentage	
9413300 – Bloomington	14	5	36	50
9413600 – Ab. I15 Restarea	17	1	6[1]	Not applicable
9413650 – Bel. I15 Restarea	17	1	6[1]	Not applicable
9413800 – Mouth of Narrows	25	14	56	90
9415000 – Littlefield	103	57	55	140
310037 – Mesquite	24	17	71	175
310032 - Riverside	24	16	67	150

[1] Exceedances of standard at Sta. 9413600 and Sta. 9413650 were lower that at the other locations due to limited sampling during low flow period

There are minimal data available to define the relationship between total boron and dissolved boron concentrations in the Virgin River. Historically, the USGS has tested for dissolved boron and NDEP has tested for total boron in the Virgin River. Only recently (1999), NDEP began testing for both total recoverable boron and dissolved boron, and the laboratory results are inconclusive. In some instances, the dissolved boron concentrations were shown to be slightly greater than the total boron concentrations (see Appendix A). This discrepancy in the data is the result of utilizing two different laboratory techniques for quantifying dissolved and total boron. Nonetheless, the data still suggest that most if not all of the total recoverable boron in the river appears in the dissolved form.

Target Analysis

Section 303(d) (1) of the Clean Water Act states that TMDLs "shall be established at a level necessary to implement the applicable water quality standards." A purpose of the target analysis is to identify those future conditions needed for compliance with the water quality standards. According to the U.S. EPA (1999), one of the primary goals of target analysis are to clarify whether the ultimate goal of the TMDL is to comply with a numeric water quality criterion, comply with an interpretation of a narrative water quality criterion, or attain a desired condition that supports meeting a specified designated use.

As discussed earlier, NAC 445A.144 provides numeric criteria for total recoverable boron concentrations as needed to support two different beneficial uses, i.e. irrigation and watering of livestock. Of the two criteria, the boron standard of 750 µg/l for irrigation is the most restrictive. According to the Gold Book (U.S. EPA, 1986), boron is an essential element for the growth of plants, however higher levels may have toxic impacts to sensitive crops. The criterion of 750 µg/l is thought to protect sensitive crops during long-term irrigation. The ultimate goal of this Lower Virgin River Boron TMDL is to comply with the numeric standard of 750 µg/l to support irrigation uses.

Source Identification and Assessment

The objective of this section is to identify boron sources in the Lower Virgin River basin, and to characterize the contribution of these sources.

Existing Point Sources and Nonpoint Sources in Nevada

Upon searching of the Nevada Bureau of Water Pollution Control's permits database, no point source discharges to the Virgin River within Nevada were discovered. However, two facilities with potential groundwater discharges have been identified as shown in Table 7.

Table 7. Active Discharges within the Lower Virgin River Basin (Nevada Portion)

Permit Number	Permittee	Facility Type	Discharge
NEV 40011	City of Mesquite, NV	Municipal Wastewater Treatment	Reuse (golf course and landscape)
Application Submitted	Bunker Farm Dairy	CAFO (Concentrated Animal Feeding Operation)	Evaporation

Source: Nevada Bureau of Water Pollution Control files

Mesquite Wastewater Treatment Plant. Until recently, the City of Mesquite Wastewater Treatment Plant (MWTP) used Rapid Infiltration Basins (RIB) for a portion of their disposal needs. These RIBs were located within a few hundred feet of the Virgin River and during their operation likely contributed to flow in the river. Recent Discharge Monitoring Reports (DMRs) indicate that effluent flows have averaged about 1.5 mgd or about 2 cfs. If all of this effluent eventually entered the river, it would have accounted for about 5 percent of the flow during very low flow periods in the Virgin River or about 1 percent of the average annual flow. The historic boron concentrations in the effluent and the potential for boron contributions to the Virgin River are not known as MWTP has not been required to monitor for boron concentration levels. However due to the low flow contribution, historic boron loads from MWTP to the Virgin River were probably small.

Since there are no industrial facilities served by MWTP, it appears that any boron load in the wastewater is the result of boron in the drinking water supply and/or sewer line infiltration. Unfortunately, no data exist to accurately quantify these contributions. According to the Bureau of Health Protection Services (2001), no boron data are collected for the Virgin Valley Water District water system for Safe Drinking Water Act compliance. Nevertheless, it is possible that the area water supply wells contain boron at an elevated level. As previously discussed, the Arizona Department of Environmental Quality (1999) found boron in the Littlefield aquifer with a median concentration of about 1,100 μg/l. Samples collected in the Virgin River alluvium had a median boron concentration of about 800 μg/l.

While the MWTP may have provided boron loads to the Virgin River in the past, the potential for treated wastewater entering the groundwater and subsequently the Virgin River has been greatly reduced. According to Icyl Mulligan, permit writer with NDEP (2001), the City of Mesquite has recently (1999) switched to full reuse of the treated wastewater with sprinkler application of the reuse water.

Bunker Farm Dairy. As required by Nevada Administrative Code 445A.228(3)(a), Bunker Farm Dairy has applied for a discharge permit for their operations. According to the permit application, wastewater (with an average discharge of 30 gpm) is generated by dairy barn and pen cleaning operations and is disposed of via evaporation ponds. Any possible boron contribution from this operation is likely to be minimal.

Irrigation Return Flows. Three main canals provide irrigation water for about 3,300 acres of irrigated land between Littlefield, Arizona and Riverside, Nevada (Las Vegas Valley Water District, 1992). The consumptive use by these crops was estimated to be about 13,000 acre-feet per year (Glancy and Van Deburgh, 1969). Assuming an irrigation efficiency of about 50 percent, return flows from these lands are estimated to be about 13,000 acre-feet per year (about 10 percent of the average annual flow in the Virgin River. Though no water quality data could be located, it is expected that boron levels in the return flows would be at least equal to those levels in the Virgin River. Since boron naturally occurs in the soils of the arid west (Carlos, 2000), the return flows may increase in boron levels as they move through the subsurface to the river. According to EPA (1975), boron compounds tend to accumulate in aquatic ecosystems due to their relatively high solubility.

Summary. Based upon this information, any boron loading to the Nevada portion of the Virgin River is considered to come from natural sources (e.g. springs, tributary inflows, groundwater inflows) and nonpoint sources (e.g. irrigation return flows). In the past the Mesquite Wastewater Treatment Plant may have contributed minor amounts to the total boron load in the Virgin River. However with its conversion to total reuse, the wastewater treatment plant's current boron contribution is likely to be insignificant.

Load Locations and Amounts

In this section, the available data were examined in an attempt to quantify changes in concentrations and loads within various river reaches, and to identify source contribution locations and amounts. Boron was assumed to be a conservative constituent[3] in all of the comparisons presented below.

[3] Conservative pollutants do not decay or degrade due to natural processes in the stream. As such, conservative pollutant loads in the water column remain essentially constant in a given parcel of water as that parcel moves downstream (assuming no additional loads are added by point and nonpoint sources, or are removed as the result of water diversions). Nonconservative pollutants (such as organic compounds) can decay over time.

Bloomington, UT to Littlefield, AZ: The only period in which concurrent dissolved boron data are available at a number of sites on the Virgin River is 1977-79. During this period, 14 of the data points for Bloomington and Littlefield occurred on the same days.

For these 14 days, the average daily loads at Bloomington and Littlefield were calculated at 479 and 655 pounds per day, respectively, using the following equation:

Load (in pounds per day) =
5.396 x boron concentration (in µg/l) x average daily flow (in cfs) / 1,000 [Eq. 1]

While this approach indicates a boron load increase from Bloomington and Littlefield, there are some limitations with this approach: 1) the associated water samples were not collected following a Lagrangian[4] sampling scheme; and 2) errors in the streamflow gaging stations introduce error into the load estimation.

Using another approach, boron concentrations at Bloomington, Utah (1977-79) were plotted versus boron concentrations at the other downstream monitoring stations (Figure 9). These data suggest that boron concentrations increase from Bloomington to Littlefield during higher flows (lower boron concentrations) and decrease during lower flows (higher boron concentrations).

Upstream of Littlefield, flow from the Littlefield Springs enters the Virgin River and contribute significantly to the flow during low periods. Unfortunately, no boron data for the Littlefield Springs could be identified for the purpose of estimating the Springs' load contribution in this reach of the Virgin River. However since most boron standard exceedances occur during low flows, Littlefield Springs flow can be identified as a major cause of standard violations in this reach of the Virgin River.

Littlefield, AZ to Mesquite, NV: At this point, there are not sufficient data to quantify changes in boron concentrations and loads between Littlefield, Arizona and the Arizona-Nevada stateline. Boron analyses at the Littlefield station were discontinued in 1982 and only recently reactivated in 1999. Of the four samples collected during 1999 at Littlefield, only one is close in timing to samples collected by NDEP at Mesquite and Riverside.

An attempt was made to compare concentration versus flow relationships for the Littlefield and Mesquite stations as a means to characterize concentration changes (Figure 10). Regression curves fitted to the data suggest that for a given streamflow, boron concentrations could be expected to be higher at Mesquite, NV than at Littlefield, AZ. However, it must be noted that these curves do not completely explain the boron-streamflow relationships, and that some uncertainty is associated with any boron concentration estimated utilizing these curves. In fact when considering the uncertainty in these relationships, no differences between estimated boron concentrations at Littlefield and Mesquite can be demonstrated using these regression curves.

[4] A Lagrangian sampling scheme consists of sampling a single parcel of water as it moves down through the river system.

Figure 9. Dissolved Boron Concentrations at Bloomington, UT versus Downstream Stations (1977-79)

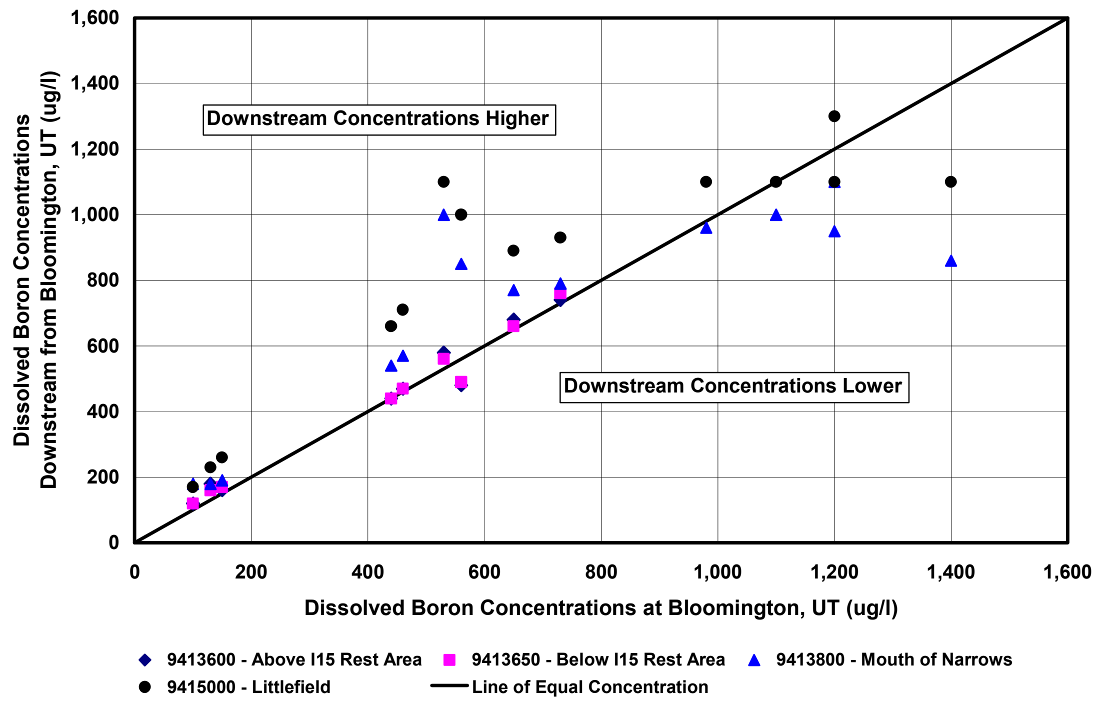
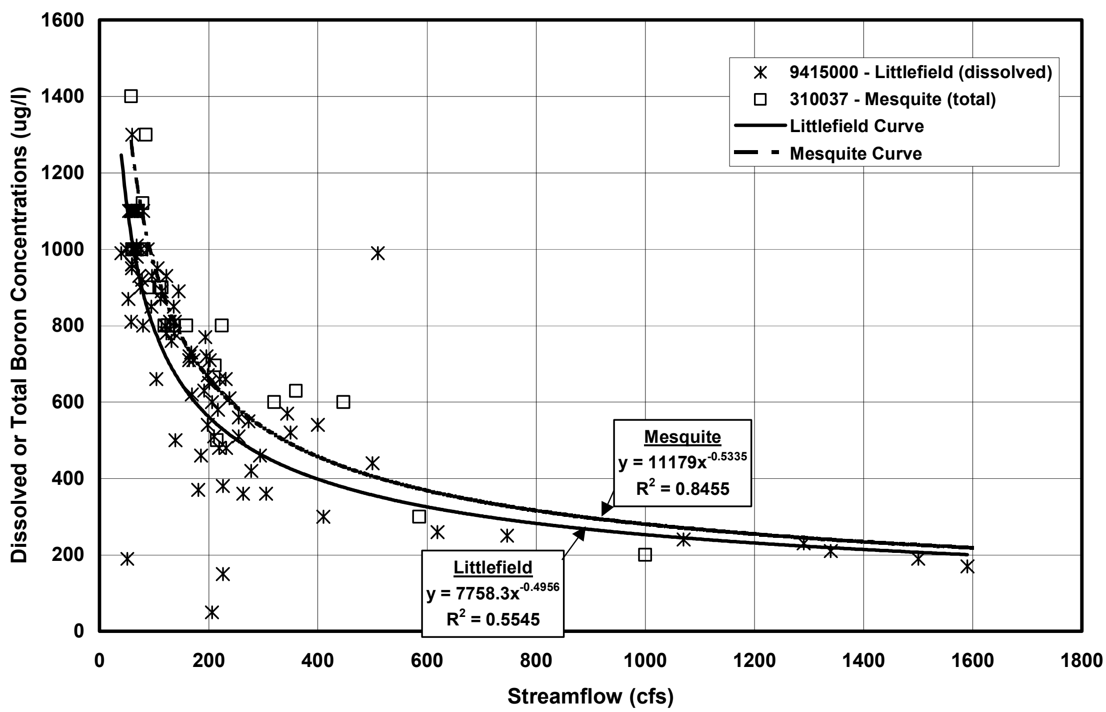


Figure 10. Boron Concentrations at Littlefield and Mesquite versus Streamflow at Littlefield



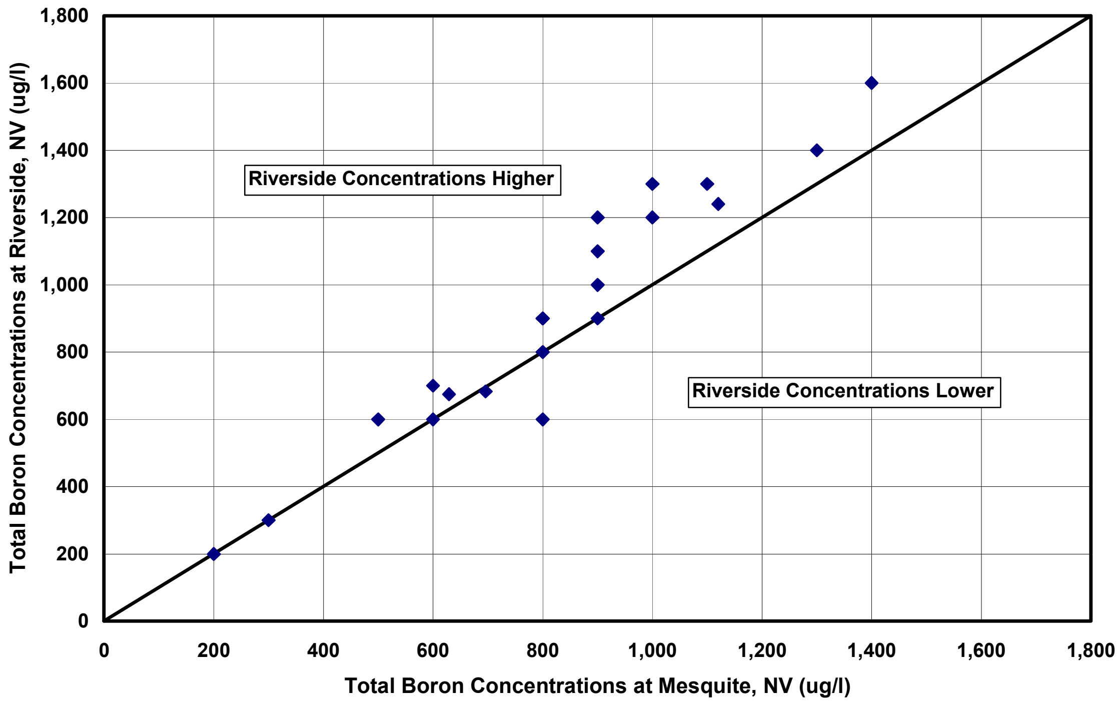
The use of this approach is further complicated by the lack of concurrent flow data collected at the Mesquite monitoring site. Due to the lack of flow data for the Mesquite site, the Mesquite flow-boron curve was developed using streamflow as measured at Littlefield. However, the Littlefield gaging station flow may not be representative of flows at Mesquite due to diversions and inflows between the two locations. It is likely that the actual flows during the sample collection at Mesquite was somewhat lower than at Littlefield. Under that scenario, the Mesquite flow-boron curve (Figure 10) would have to be shifted to the left making it closer to the Littlefield curve.

In summary, data do not exist to accurately show whether or not boron loading occurs to any significant level in this reach. However, the data do suggest that loading in this reach is small compared to any loading entering the reach at Littlefield. If boron loading does occur in this reach, possible sources include: 1) Mesquite Wastewater Treatment Plant RIBs (historic loading only); 2) irrigation return flows; and 3) natural surface water and groundwater discharge. It must be noted that any possible increases in the total boron concentrations from Littlefield to Mesquite could be due to natural water losses (evaporation, evapotranspiration, etc.) and anthropogenic losses (irrigation consumptive use) that are concentrating the boron in the stream.

Mesquite, NV to Riverside, NV: For the Mesquite and Riverside monitoring stations, concurrent total boron data exists for the period 1990 to 2000. However, there are limited streamflow data associated with these grab samples. A majority of the streamflow data presented in Appendix A is for the Littlefield, AZ gaging station and may not be an accurate representation of flows at Mesquite and Riverside due to water diversions and other inflows between Littlefield and these stations. Nevertheless “rough” estimates of boron loads at Mesquite and Riverside were developed using NDEP water quality data and Littlefield flows. For the sampled days, the loads at Mesquite and Riverside averaged about 690 and 740 pounds per day, respectively. While this calculation suggests a load increase of about 7 percent, the results are misleading. Significant irrigation diversions and other losses occur between Mesquite and Riverside. After accounting for these diversions and the resulting reduction in the flow, the actual load at Riverside for those sampled days was probably lower than the 740 pounds per day estimated using Littlefield flows, and may have been lower than the load at Mesquite.

Another approach was taken involving the examination of changes in concentrations. For the sampling period 1990 to 2000, many of the samples at Mesquite had higher total boron concentrations than those at Riverside (Figure 11). The average boron concentration at Riverside was about 10 percent higher than the average Mesquite concentration. However, the available data may not be adequate for determining whether or not boron concentrations increase between Mesquite and Riverside due to certain limitations: 1) water samples were not collected following a Lagrangian sampling scheme; and 2) there are errors inherent in the sampling and laboratory analysis. Of the 24 samples tested, about 40 percent of the Riverside samples had total boron concentrations less than or within 10 percent of the Mesquite samples.

Figure 11. Total Boron Concentrations at Mesquite, NV versus Riverside, NV



In summary, the data do not exist to accurately show whether or not boron loading occurs to any significant level in this reach. However, the data do suggest that loading in this reach is small compared to any loading entering the Virgin River at and above Littlefield. If boron loading does occur in this reach, possible sources include: 1) irrigation return flows; and 2) natural surface water and groundwater discharge. It must be noted that any possible increases in the total boron concentrations from Mesquite to Riverside could be due to natural water losses (evaporation, evapotranspiration, etc.) and anthropogenic losses (irrigation consumptive use) that are concentrating the boron in the stream. As shown in Table 4, average annual flows decrease by about 12 percent from Littlefield to the Riverside area.

Other Load Characteristics

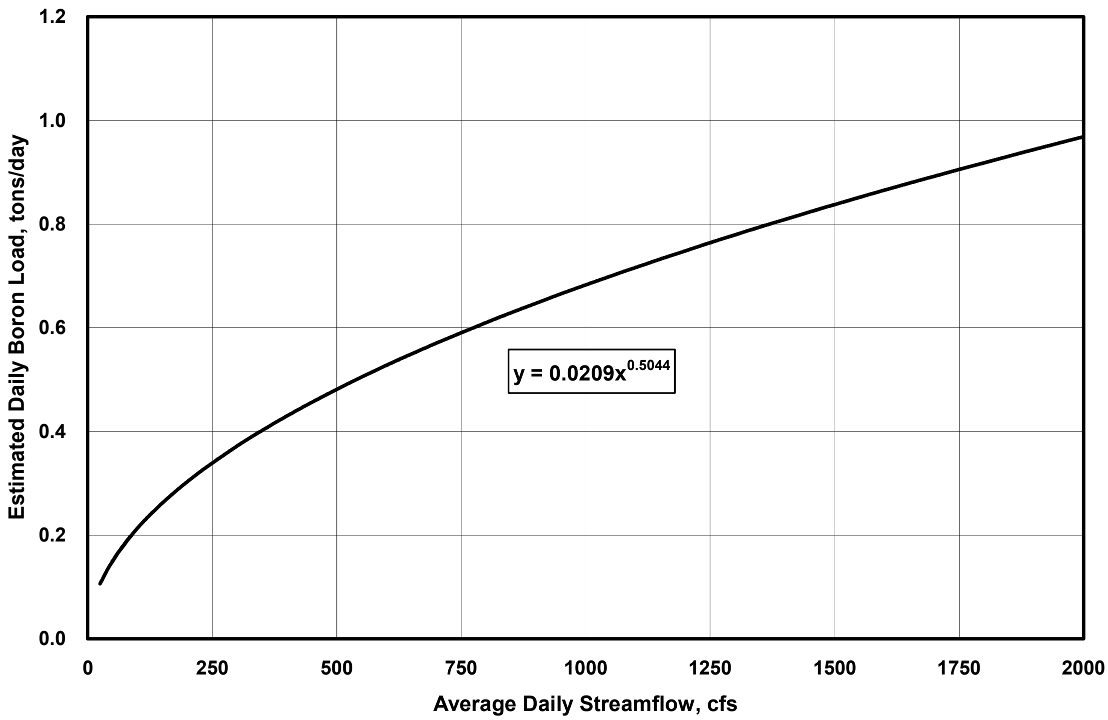
Dissolved boron concentrations at Littlefield, AZ decrease with increases in streamflow as represented with the following equation (Figure 10):

$$\textit{Dissolved Boron Concentration (in } \mu g/l\textit{) = 7,758 x Streamflow (in cfs)}^{-0.4956} \quad \text{[Eq. 2]}$$

This inverse relationship between boron concentrations and flow exists at the other monitoring stations discussed in this report (see Appendix C). Another form of Equation 2 allows for the estimation of loads for a given streamflow (Figure 12):

$$\textit{Daily Dissolved Boron Load (in tons/day) = 0.0209 x Average Daily Streamflow (in cfs)}^{0.5044} \quad \text{[Eq. 3]}$$

Figure 12. Dissolved Boron Load versus Flow at Littlefield, AZ



While boron concentrations decrease with streamflow (Figure 10), boron loads at Littlefield generally increase as flows increase as shown in Figure 12. As previously discussed, streamflows varies throughout the year with the lowest flows typically occurring from June through October. The lowest boron loads also occur during this same period as shown on the plot of monthly boron loads estimated using Equation 3 (Figure 13).

Summary and Conclusions

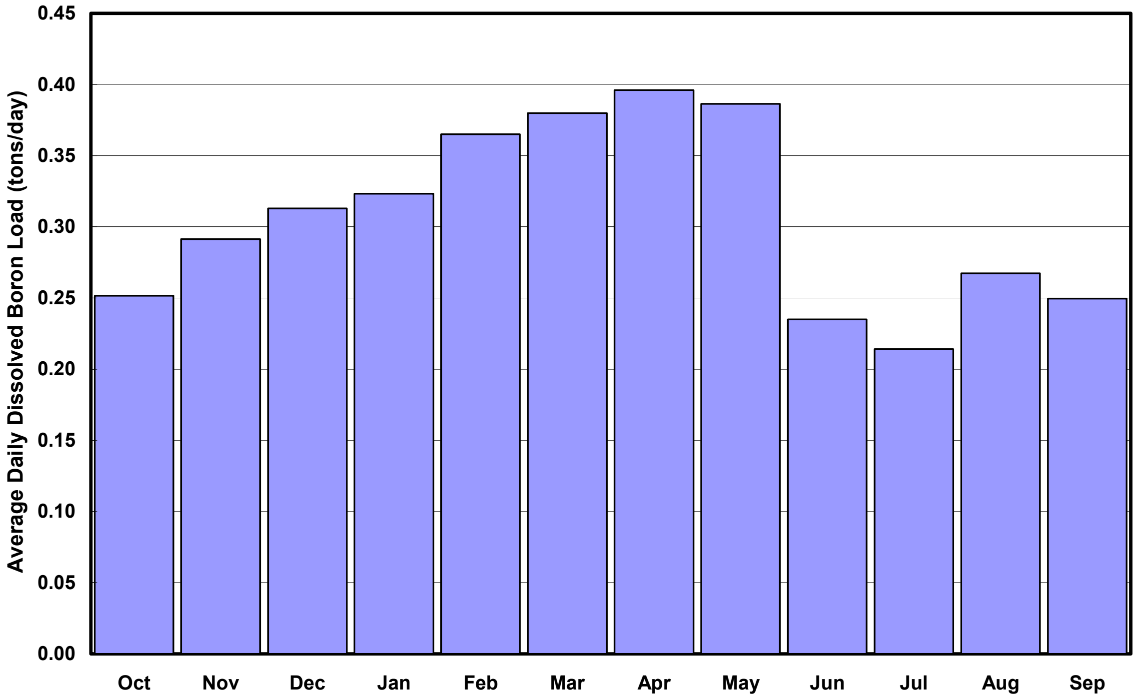
It is difficult to characterize boron loadings in the Lower Virgin River for a number of reasons:

- lack of current data;
- lack of concurrent streamflow data; and
- existing data were not collected following any kind of Lagrangian sampling scheme.

However based upon the available data and information, the following conclusions regarding boron concentrations and loadings to the river can be made with some confidence:

- A majority of the boron in the Virgin River is in the dissolved form. This would indicate that the boron in the Virgin River is not tied up with sediment and particulate matter and that boron in the river is not the result of erosional processes.

Figure 13. Estimated Average Daily Dissolved Boron Load - Virgin River at Littlefield, AZ (09415000)



- Boron concentrations exceeding Nevada's water quality standard have occurred throughout the Virgin River system in Utah, Arizona and Nevada.
- Boron concentrations decrease with increases in streamflow. In other words, higher flows generally dilute the boron sources entering the Virgin River. A majority of the boron standard exceedances occurred during periods of flow less than 50 to 175 cfs. It is during these times when Littlefield Springs contributes significantly to the overall flow and is a primary boron source.
- The data suggest that the boron loading observed at the Mesquite and Riverside monitoring stations originates primarily in Utah and Arizona. It appears that minimal boron loading, if any, occurs in Nevada.
- Boron loads are not constant but vary with flows, increasing as flows increase.
- Groundwater in the region has high boron levels. Natural groundwater discharge to the river contributes to the boron loads.
- Any increase in boron loads from Littlefield to Lake Mead can not be accurately quantified from the available data. However, the data show that boron concentrations may increase as the river flows through Nevada. Nevertheless, increases in boron concentrations may be due to natural water losses (evaporation, evapotranspiration, etc.) that are concentrating the boron in the stream, and not any additional load to the stream. It is unknown if irrigation return flows below Arizona "pick-up" additional boron as the water flows through the alluvium. However, it is known that the water used for irrigation already contains high concentrations of boron during low flow periods.

Linkage of Source and Target

The purpose of this section is to:

- examine receiving water response to loadings under historic and current levels; and
- analyze the assimilative capacity (how much loading the system can receive without violating the water quality standards) of the stream.

Establishing the relationship between the water quality target and pollutant loads allows an estimation of the degree to which historical and existing loads exceed allowable loads, and the associated degree of pollution reduction needed to attain water quality standards (EPA, August 1999).

Historic Loads and Response

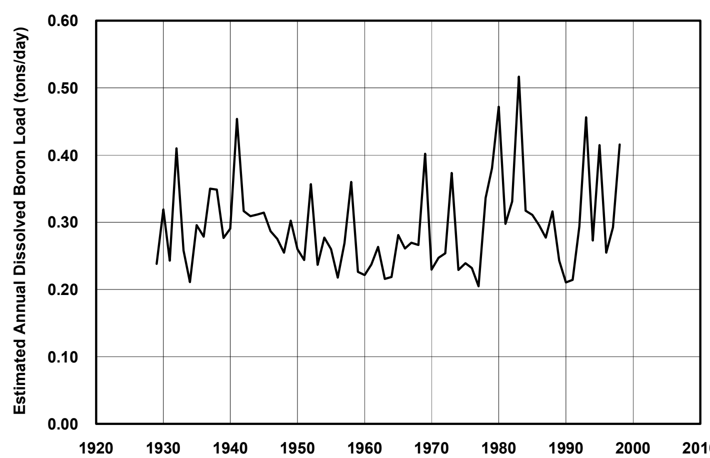
For this analysis, boron was assumed to be a conservative substance (does not decay or degrade due to natural processes in the stream). In other words, all boron loading to the river stays in the river (except for that portion included in water diverted for use) and moves downstream with the flow.

As shown on Figure 12, dissolved boron loads at Littlefield, AZ for a given streamflow can be estimated using the following equation:

Daily Dissolved Boron Load (in tons/day) = 0.0209 x Average Daily Streamflow (in cfs) $^{0.5044}$ [Eq. 4]

Utilizing Equation 4 with available average daily streamflow data, estimated annual loads at Littlefield, AZ were calculated for 1930-98 (Figure 14). During this period, annual dissolved boron loads averaged about 0.29 tons/day, and varied from a minimum of about 0.20 tons/day to a maximum of 0.52 tons/day.

Figure 14. Estimated Annual Dissolved Boron Loads at Littlefield, AZ



Maximum Allowable Loads

The total amount of boron (load) that the river can receive on any given day, without violating the boron water quality standard (750 µg/l), can be expressed by the following equation:

Allowable Boron Load (tons/day) = 0.0027 x Average Daily Flow (cfs) x 0.750 mg/l [Eq. 5]

Using an average daily streamflow of 245 cfs for 1930-98, this equation results in an allowable boron load of about 0.50 tons per day at Littlefield, AZ. This is considerably higher than the historic average load of 0.29 tons per day. Based upon this approach, no load reduction would be necessary for compliance with the boron standard. However, the data clearly show that Nevada's boron standard is frequently violated throughout the Lower Virgin River during low flows, and that load reductions during these low flow periods would improve compliance with the standard. For this reason, maximum allowable loads were calculated for various flow ranges (Table 8). Maximum allowable load values were restricted to flows ranging from 40 cfs to 175 cfs because: 1) historic minimum flows in the Virgin River are 40 cfs (Figure 4); and 2) most of the standard exceedances have occurred during flows less than 175 cfs.

Table 8. Allowable Boron Loads for Various Flow Ranges

Flow Range, cfs	Average Flow, cfs	Average Allowable Load, tons per day
40 to 75	57.5	0.127
75 to 100	87.5	0.177
100 to 125	112.5	0.228
125 to 150	137.5	0.278
150 to 175	162.5	0.329

Note: Average allowable loads were calculated by applying the average flow for each range to Equation 5.

Pollutant Load Allocation

In the development of the TMDL, allowable allocations (as needed to meet the water quality standards) are to be defined for the various sources. The total load allocation is defined as the sum of wasteload allocations to point sources, load allocations to nonpoint and natural background sources. A margin of safety is to be included in the analysis, and due consideration is to be given to seasonal variations and critical conditions.

The previous analyses have revealed no point or quantifiable nonpoint sources of boron to the Virgin River in Nevada, and that water quality impairment due to boron is primarily the result of loading in Utah and Arizona. No attempt has been made to quantify boron loads in Utah and Arizona by category (point sources, nonpoint sources, and natural background sources).

The goal of a TMDL is to allocate pollutant loads and (through its implementation plan) define a set of actions such that water quality standards will be achieved. With no identifiable sources in Nevada, the boron water quality standard is only achievable through actions taken in Utah and Arizona. Therefore, only gross (point, nonpoint, and natural source allocations lumped) load allocations have been set for the Nevada-Arizona stateline. A margin of safety and seasonal variations were considered in the allocation process as discussed below.

Margin of Safety

Load allocations are to include either an explicit or implicit margin of safety (MOS) to account for uncertainty in determining the relationship between discharges of pollutants and impacts on water quality. An explicit MOS can be provided in the following ways:

- setting numeric targets at more conservative levels than analytical results indicate;
- adding a safety factor to pollutant loading estimates; or
- reserving a portion of the loading capacity to the MOS and not allocating this portion to the sources.

An implicit MOS can be incorporated into the allocation process by:

- using conservative assumptions in derivation of numeric targets;
- using conservative assumptions when developing numeric model applications; or
- using conservative assumptions when analyzing prospective feasibility of practices and restoration activities (U.S. EPA, August 1999).

The load allocation in this report incorporated an explicit MOS of 15% in the analysis. This MOS is intended to primarily account for uncertainties and errors in the boron versus streamflow relationship (Equation 2) used to calculate historic loads:

- Equation 2 does not completely explain the relation between boron and flow as evidenced by the coefficient of determination (R^2) of 0.5545.
- Equation 2 was based upon dissolved boron rather than total boron.

Seasonal Variations and Load Allocations

Previous sections have discussed how boron concentrations in the Virgin River decrease with increases in flow. As a result, most of the boron standard exceedances occur when flows are below 175 cfs, which typically occurs from June to October. It is only during these periods that load reductions are needed to meet the boron water quality standards.

Table 8 presents the maximum allowable loads for selected flow ranges. By comparing estimated historic loads to these maximum allowable loads along with margin of safety considerations, load reductions were calculated for the various flow ranges (Table 9). The following equations were used to calculate the MOS, Gross Load Allocation and Load Reductions:

$$\textit{MOS (tons/day)} = \textit{Average Allowable Load (tons/day)} \times 15\% \qquad \text{[Eq. 6]}$$

$$\textit{Gross Load Allocation (tons/day)} = \textit{Average Allowable Load (tons/day)} - \textit{MOS (tons/day)} \qquad \text{[Eq. 7]}$$

Load Reduction (tons/day) = Average Historic Load (tons/day)
– Gross Load Allocation (tons/day) [Eq. 8]

Due to the inverse relationship between flow and boron concentrations, needed load reductions are highest with the lower flows. At flows above about 125 cfs, no load reductions are calculated. Historically, boron standard exceedances have occurred during flows greater than 125 cfs, however it must be noted that the "average historic load" in Table 9 is based upon Equation 1 which approximates the relationship between boron concentrations and flow. Based upon Equation 1, a boron concentration of 750 µg/l is predicted when flow is at 111 cfs, with even lower boron levels at higher flows.

Table 9. Boron Load Allocation at Stateline and Load Reductions for Various Flow Ranges

Flow Range, cfs [1]	Average Historic Load, tons per day [2][1]	Average Allowable Load, tons per day [3][2]	Margin of Safety, tons per day [4] = [3] * 15%	Gross Load Allocation, tons per day [5] = [3] - [4]	Load Reduction Needed, tons per day [6] = [2] – [5]
50 to 75	0.168	0.127	0.019	0.108	0.060
75 to 100	0.199	0.177	0.027	0.150	0.049
100 to 125	0.226	0.228	0.034	0.194	0.032
125 to 150	0.250	0.278	0.042	0.236	---
150 to 175	0.272	0.329	0.049	0.280	---

[1] Average historic load estimated using Equation 3 with average flow rate. Equation 3 was developed to estimate dissolved boron loads at Littlefield, AZ. Total recoverable boron loads may be higher.
[2] Average allowable load estimated using Equation 5.

Summary

The goal of a TMDL is to allocate pollutant loads and (through its implementation plan) define a set of actions such that water quality standards will be achieved. However with minimal boron sources in Nevada, the boron water quality standard cannot be achieved until implementation actions are taken in Utah and Arizona. For that reason, only gross (point, nonpoint, and natural source allocations lumped) load allocations needed to meet Nevada water quality standards have been set for the Nevada-Arizona stateline.

Without boron load reductions in Utah and Arizona, the boron standard can not be met in Nevada's portion of the Virgin River. The feasibility of meeting Nevada's boron standards at the Nevada-Arizona stateline is unknown. Further analysis of the boron sources in Utah and Arizona is needed for better characterization of the problem, including the identification of natural and anthropogenic boron sources, and analyses of implementation options.

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Appendix A

Summary of Streamflow Regression Equations for Water Budget

Appendix A. Summary of Streamflow Regression Equations for Water Budget

An approximate surface water budget was developed for the Virgin River for the period 1930-98. For those stations with incomplete data available during this period, the following regression equations were used to develop estimates of those missing data points. Annual flow values are in acre-feet.

Station Name: Virgin River near Bloomington, UT
Historic Period of Record: 1997-98
Equation Used to Estimate Flow for Missing Years:

*Annual Flow at Bloomington = 0.921 * Annual Flow at Littlefield – 20,100*

where: $R^2 = 0.964$

Station Name: Virgin River at St. George, UT
Historic Period of Record: 1951-57, 1992-96, 1998
Equation Used to Estimate Flow for Missing Years:

*Annual Flow at St. George = 0.884 * Annual Flow at Littlefield – 21,200*

where: $R^2 = 0.986$

Station Name: Virgin River at Riverside, NV
Historic Period of Record: 1971-74, 1993-96
Equation Used to Estimate Flow for Missing Years:

*Annual Flow at Riverside = 0.943 * Annual Flow at Littlefield – 10,700*

where: $R^2 = 0.977$

Station Name: Virgin River at Halfway Wash near Riverside, NV
Historic Period of Record: 1978, 1980-83, 1985
Equation Used to Estimate Flow for Missing Years:

*Annual Flow at Halfway Wash = 0.813 * Annual Flow at Littlefield – 11,600*

where: $R^2 = 0.964$

Appendix B

Boron and Streamflow Data at Primary Monitoring Locations

Table B-1. Virgin River at Bloomington, UT (STORET ID 9413300)

Date	Dissolved Boron as B, ug/l (STORET ID 1020)	Instantaneous Streamflow, cfs (STORET ID 0061)
05/23/78	150	882
06/20/78	530	145
07/27/78	1,200	25
08/22/78	1,400	30
09/26/78	1,200	43
10/23/78	650	160
11/27/78	440	165
01/22/79	460	278
04/23/79	130	1,200
05/22/79	100	1,790
06/26/79	560	138
07/25/79	980	52
08/27/79	1,100	42
10/30/79	730	130

Table B-2. Virgin River above I15 Rest Area near Littlefield, AZ (STORET ID 9413600)

Date	Dissolved Boron as B, ug/l (STORET ID 1020)	Instantaneous Streamflow, cfs (STORET ID 0061)
11/10/77	700	45
12/14/77	770	22
01/24/78	470	127
02/13/78	280	220
03/28/78	240	591
04/25/78	160	685
05/22/78	160	820
06/20/78	580	10
10/24/78	680	95
11/28/78	440	160
12/20/78	330	269
01/23/79	470	164
02/20/79	420	215
04/23/79	180	950
05/21/79	120	1,730
06/25/79	480	82
10/29/79	740	63

Table B-3. Virgin River below I15 Rest Area near Littlefield, AZ (STORET ID 9413650)

Date	Dissolved Boron as B, ug/l (STORET ID 1020)	Instantaneous Streamflow, cfs (STORET ID 0061)
11/09/77	720	51
12/13/77	700	35
01/25/78	510	102
02/14/78	280	179
03/29/78	230	574
04/25/78	190	549
05/23/78	170	880
06/20/78	560	9
10/24/78	660	84
11/28/78	440	154
12/20/78	300	276
01/23/79	470	144
02/21/79	400	231
04/24/79	160	924
05/22/79	120	1,620
06/26/79	490	25
10/30/79	760	64

Table B-4. Virgin River at Mouth of Narrows near Littlefield, AZ (STORET ID 9413800)

Date	Dissolved Boron as B, ug/l (STORET ID 1020)	Instantaneous Streamflow, cfs (STORET ID 0061)
09/20/77	1,000	16
10/19/77	1,100	19
11/09/77	820	56
12/13/77	790	46
02/14/78	310	215
03/29/78	250	610
04/26/78	210	585
05/24/78	190	485
06/21/78	1,000	20
07/26/78	950	18
08/23/78	860	17
09/26/78	1,100	19
10/25/78	770	96
11/29/78	540	154
12/19/78	190	900
01/24/79	570	150
02/22/79	430	450
03/21/79	330	720
04/24/79	180	1,200
05/23/79	180	1,700
06/27/79	850	34
07/26/79	960	23
08/28/79	1,000	23
09/25/79	1,000	23
10/31/79	790	86

Table B-5. Virgin River at Littlefield, AZ (STORET ID 9415000)

Date	Dissolved Boron as B, ug/l (STORET ID 1020)	Mean Daily Streamflow, cfs (STORET ID 0061)	Instantaneous Streamflow, cfs (STORET ID 0061)	Date	Dissolved Boron as B, ug/l (STORET ID 1020)	Mean Daily Streamflow, cfs (STORET ID 0061)	Instantaneous Streamflow, cfs (STORET ID 0061)
07/17/54	150	226		01/29/74	660		231
08/13/54	370	181		03/12/74	670		198
05/01/59	1,000	65		03/25/74	800		120
09/01/60	800	80		04/28/74	1,000		68
09/02/60	990	510		05/30/74	1,100		60
02/28/62	510	210		06/20/74	1,100		64
05/09/62	460	186		07/30/74	1,100		58
08/22/62	190	51		08/20/74	1,100		63
12/18/65	510	255		08/23/74	1,100		64
03/12/66	380	226		09/25/74	1,100		60
04/13/66	480	232		10/18/74	1,100		58
06/22/66	810	58		01/14/75	870		112
06/23/66	960	59		01/23/75	810		138
09/20/66	950	59		02/13/75	730		168
10/21/67	890	114		03/19/75	580		217
01/15/68	600	206		04/03/75	720		165
01/30/68	50	206		04/28/75	900		75
04/13/68	420	278		05/15/75	540		198
05/23/68	480	219		05/20/75	460		294
07/04/68	870	53		06/20/75	1,000		66
10/01/68	960	60		06/21/75	1,000		60
11/05/68	850	95		07/10/75	1,000		50
11/26/68	780	122		09/20/77	1,100		57
01/18/69	650	201		11/09/77	950		106
03/30/69	210	1,340		12/13/77	930		96
10/02/69	930	73		01/25/78	710		164
10/04/69	990	40		02/13/78	300		410
01/19/70	610	238		04/26/78	250		747
02/18/70	760	132		05/24/78	260		619
03/20/70	780	137		06/21/78	1,100		63
04/23/70	980	68		07/26/78	1,100		60
05/21/70	1,100	66		08/23/78	1,100		54
06/18/70	1,100	70		09/28/78	1,300		60
07/15/70	1,010	68		10/25/78	890		145
08/27/70	1,000	76		11/29/78	660		104
09/25/70	1,000	68		12/19/78	240		1,070
01/15/71	630	192		01/24/79	710		202
10/18/71	550	273		02/22/79	500		139
11/23/71	720	196		04/24/79	230		1,290
05/25/72	1,100	64		05/23/79	170		1,590
09/12/72	1,000	64		06/27/79	1,000		88
10/16/72	440	500		07/26/79	1,100		71
11/16/72	540	400		08/28/79	1,100		70
12/18/72	770	194		10/31/79	930		122
01/30/73	710	172		08/28/81	1,100		71
02/28/73	520	350		10/21/81	850		136
04/04/73	570	344		09/03/82	1,100		80
04/30/73	190	1,500		01/26/99	560		255
06/19/73	360	263		03/02/99	620		169
10/25/73	1,100		68	05/05/99	360		305
12/04/73	660		220	06/22/99	920		78
				08/24/99	810		129

Table B-6. Virgin River at Mesquite, NV (STORET ID 310037)

Date	Dissolved Boron as B, ug/l (STORET ID 1020)	Total Boron as B, ug/l (STORET ID 1022)	Mean Daily Streamflow at 9415000 (Virgin River at Littlefield, AZ)
07/25/90		1,000	60
01/31/91		800	119
08/06/91		1,400	58
01/29/92		800	159
07/22/92		1,300	85
01/27/93		500	215
07/21/93		900	90
01/26/94		800	135
07/27/94		1,000	75
01/26/95		600	447
05/24/95		200	1000
07/26/95		800	125
02/06/96		600	320
08/21/96		1,100	71
01/28/97		300	586
05/20/97		900	114
07/29/97		1,120	79
01/27/98		696	211
07/28/98		629	360
01/25/99	700	800	224
07/27/99	1,000	900	110
01/25/00	900	800	
07/25/00	1,000	900	
01/23/01	800	800	

Table B-7. Virgin River at Riverside, NV (STORET ID 310032)

Date	Dissolved Boron as B, ug/l (STORET ID 1020)	Total Boron as B, ug/l (STORET ID 1022)	Mean Daily Streamflow at 9415000 (Virgin River at Littlefield, AZ)	Mean Daily Streamflow at 9415190 (Virgin River at Riverside, NV)
07/25/90		1,300	60	
01/31/91		900	119	
08/06/91		1,600	58	
01/29/92		800	159	
07/22/92		1,400	85	
01/27/93		600		248
07/21/93		1,000		23
01/26/94		900		147
07/27/94		1,200		3
01/26/95		700		278
05/24/95		200		1000
07/26/95		900		52
02/06/96		600	320	
08/21/96		1,300	71	
01/28/97		300	586	
05/20/97		900	114	
07/29/97		1,240	79	
01/27/98		683	211	
07/28/98		675	360	
01/25/99	700	600	224	
07/27/99	1,200	1,100	110	
01/25/00	900	900		
07/25/00	1,300	1,200		
01/23/01	900	800		

Appendix C

Summary of Boron vs. Streamflow Regression Equations

Appendix C. Summary of Boron vs. Streamflow Regression Equations

The data from all seven water quality monitoring stations identified in the report show that boron concentrations increase with decreases in streamflow as quantified with the following regression equations:

Station Name: Virgin River at Bloomington, UT

*Boron Concentrations (µg/l) = 11,910 * Streamflow* $^{-0.6242}$
Where $R^2 = 0.966$

Station Name: Virgin River above I-15 Rest Area near Littlefield, AZ

*Boron Concentrations (µg/l) = 2,727 * Streamflow* $^{-0.3897}$
Where $R^2 = 0.815$

Station Name: Virgin River below I-15 Rest Area near Littlefield, AZ

*Boron Concentrations (µg/l) = 2,317 * Streamflow* $^{-0.3655}$
Where $R^2 = 0.770$

Station Name: Virgin River at Mouth of Narrows near Littlefield, AZ

*Boron Concentrations (µg/l) = 3,506 * Streamflow* $^{-0.4023}$
Where $R^2 = 0.910$

Station Name: Virgin River at Littlefield, AZ

*Boron Concentrations (µg/l) = 7,758 * Streamflow* $^{-0.4956}$
Where $R^2 = 0.555$

Station Name: Virgin River at Mesquite, NV

*Boron Concentrations (µg/l) = 11,179 * Streamflow at Littlefield* $^{-0.3655}$
Where $R^2 = 0.846$

Station Name: Virgin River at Riverside, NV

*Boron Concentrations (µg/l) = 16,858 * Streamflow* $^{-0.5988}$
Where $R^2 = 0.885$